Water-independent frequency- and phase-corrected spectroscopic averaging using cross-correlation and singular value decomposition

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Introduction

Single voxel spectroscopy (SVS) can produce high quality spectra with a good signal to noise ratio. However, both subject restlessness and physiological processes can cause frequency and phase differences from FID to FID. Frequency shifts occur due to changing locations of susceptibility boundaries and dephasing occurs due to the velocity encoding effect of the outer volume suppression gradients. Residual water has been used as a frequency and phase reference [1,2], however, its frequency shift may not be parallel to that of the metabolites due to the relative shift of the water suppression band resulting in non-symmetric water suppression. Alternatively, [3,4] used "high SNR" metabolites to perform frequency and phase correction.

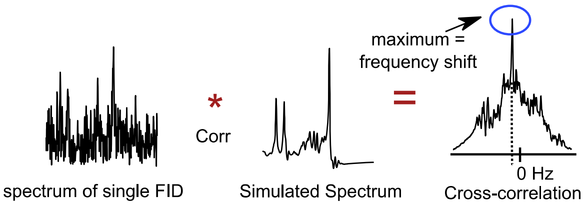

Figure 1: Cross-correlation of FID spectrum with simulated spectrum

Methods

Cross-correlation can be used to detect an expected signal in the presence of noise. In this manner the spectrum of each FID can be correlated with a simulated spectrum to robustly detect the frequency shift of the metabolites. This is demonstrated in fig. 1. Singular value decomposition (SVD) is a statistical phase independent technique that is used to determine a principal underlying signal. If **USV** = svd($\mathbf{O}_s$), where $\mathbf{O}_s$ is the spectra of the FIDs collated into a matrix, then the first column of inv(**V**) provides a set of complex weights that can be used to recombine the spectra in a weighted and phase-coherent manner. For both the cross-correlation and SVD a spectral range of -3.5 ppm to 1 ppm was used. To prevent the residual water signal from biasing the SVD, it was removed by scaling (and frequency shifting) a water sample FID, obtained from the same voxel, and subtracting it from each FID. A copy of each spectrum without the water editing was simultaneously frequency shifted and used for the recombination, such that the water editing would not be included in the final spectrum.

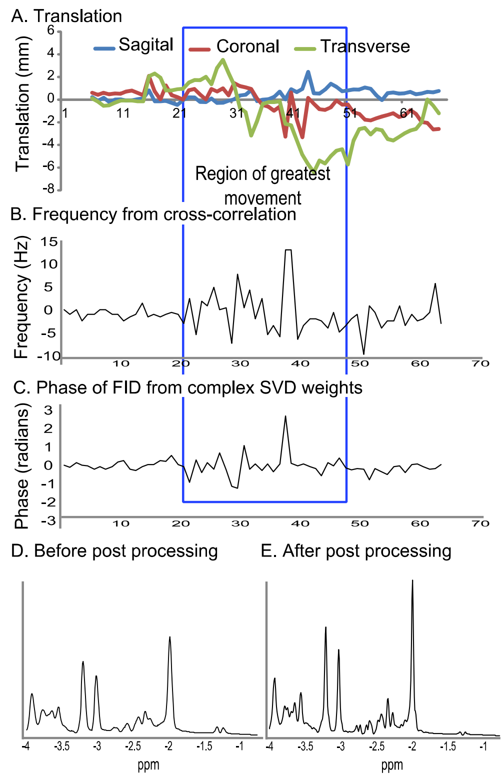

Figure 2: Translation (A). Frequency (B) and phase (C) correction measured by cross-correlation and SVD. (D) and (E) are spectra before and after post processing.

All processing was performed in Matlab (Mathworks, Natick, MA). To demonstrate this procedure we have used an SVS scan that was acquired from a 5 year old child, in accordance with our institution's ethics guidelines. The scan was performed on a 3T Siemens Allegra scanner using an EPI shim and motion navigated (vNav) PRESS sequence [5] with TE 30 ms, TR 2000 ms, 64 averages and a 15 x 15 x 15 mm^3 voxel in the peritrigonal white matter. During this scan, the subject moved repeatedly as much as 6 mm in the transverse direction (see vNav motion log in fig. 2A). While the navigator corrected the gross changes to B0, it is unable to correct within-TR movement effects.

Results, discussion and conclusion

Figure 2 shows the subject motion measured by the vNav, the frequency and phase measured by cross-correlation and SVD, respectively, and the spectrum before and after post processing. The improvement in linewidth using this method is clear, the robustness with which it detects the frequency is demonstrated in Figure 1, and has been found to be consistently robust across 60 scans thus far processed. Frequency shifts of 10 Hz, and phase shifts of 2.7 rad (154°) are observed; note that the frequency shifts were instantaneous as they are corrected by the vNav on the next TR. In conclusion, we have demonstrated a robust water-independent method to correct the frequency of each FID in an SVS scan and phase-independently recombine them.

Acknowledgements

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